Kay Ferrari: Thank you very much. Good afternoon, everyone. This is Kay Ferrari on behalf of Heather Doyle, Jeff Nee and Amelia Chapman. We'd like to welcome you to the next in our series of the Astrobiology telecons.

This one is entitled, "Exoplanet Biosignatures" and we're delighted to have with us Theresa Mason-Fisher and she is a Ph.D. student in the School of Earth and Space Exploration at Arizona State University.

She's investigating the influence of global biospheres on the topology of the chemical reaction networks of a planet's biosphere and she's doing that to find potential biosignatures for exoplanets.

So we're delighted to have you join us, Theresa.

Theresa Mason-Fisher: Oh, thank you for that lovely introduction. So as was aforementioned, I am going to be discussing exoplanet biosignatures as close to the cutting edge as I can get.

So this is a very big up and coming subfield within astrobiology and it's something there's been a lot of excitement about as I'm sure many of you know. We have cataloged more exoplanets in the last few years than we had in the entire century prior and there's new data coming in all the time and why exoplanets in particular are coming up is that if you go to **Slide 2** on the slideshow, that within the near-term future probably within the next 10 to 20 years, we are going to have the ability to get higher resolution data about exoplanets than we ever had before whether that's through the upcoming James Web Space telescope, WFirst, which recently got cancelled, but hopefully we'll get uncancelled, or the European Space Agency's Plato mission.

So essentially, this is something that previously had been entirely hypothetical, but is now becoming within our technological grasp. I should also note that it's not just limited to space telescopes as some of the next generation extremely large ground-based telescopes come online like the European extremely large telescope.

They may also potentially have the capability to image exoplanets with the level of resolution we need to start seriously talking about exoplanet biosignatures.

So how do we figure out from essentially what is a dot on a screen, a tiny spec, if that, if a planet is inhabited or not?

Well, if you turn to **Slide 3**, you'll see a very, very quick and dirty illustration of how this process works or at least how we currently do it.

So we are somewhat limited in the amount of information we can get about exoplanets right now. Obviously, we can't send a probe, at least not easily, to image the surface directly the way we could with, like, Mars or Pluto or Venus or wherever.

We can only determine a few things from Earth. It's approximate size of the planet, its mass and this is the bit that is going to hopefully be coming online in the very near future. It's the composition of its atmosphere. And the way we do this is we exploit a weird property of light and quantum mechanics.

Essentially, the idea is that if the planet's host star and us are aligned properly, the planet will pass in front of the star from our point of view and the starlight will pass through the planet's atmosphere.

Now, again, due to some quantum properties of molecules, all molecules absorb a specific wavelength of light depending on what atom it is and then what combination and it's very, very distinct for most molecules and most atoms.

And as a result, when you take the spectra, shoot the light through essentially what is a prism and you see the rainbow of colors, you'll see certain black lines in that spectra where the lights that was emitted by the star was absorbed by the gases in a planet's atmosphere.

And from this, you can usually determine with decent confidence what the planet's atmosphere is made of. This part isn't just hypothetical. It's actually been done mostly with how Jupiter is. That is a very, very large planet, extremely close to their host starts.

Usually, the host stars have been red dwarfs, so fairly dim stars as well. All of these is it's because it's a lot easier to get this information with a very large, very bright planet and a comparatively dim star.

The breakthrough or the hope we are all having about these next generation of telescopes is that we'll be able to do the same thing for much smaller, much cooler, much more distant Earth-like planets, the sort of planets where presumably there might be life.

So - and in particular this case the first ones were done with detecting sodium in the planet's atmosphere. Again, since these are extremely hot planets even in their atmospheres, even metals, like, sodium and iron are in a gaseous state that basically have been vaporized.

Obviously, you wouldn't necessarily see something like this in Earth's atmosphere. So you may be thinking to yourself, okay, great. We have this spectra. How do we tell if there's light or not? Well, that brings us to **Slide 4**, which is the problem.

Namely, how do we translate this information? How do we say, okay, we know this planet's atmosphere has a given set of gases in it whether that's oxygen or carbon dioxide or nitrogen or whatever.

How do we take that and say, okay, we see these gases; therefore, we can infer that there's life here?

Well, that's tricky and that's actually a large portion of what I'm going to be talking about today is how do we tackle that particular problem of taking a very limited set of data and saying, okay, hey, we're not alone in the universe and there are potentially a couple of different ways to do this, to take this very sparse data and look for signs of life.

The one that is probably been most discussed with in the field if you go to Page - **Slide 5** is to look for very specific trace gases. The ones we normally think about are the ones that here on Earth are associated with life, oxygen being a prime example.

The vast, vast, vast majority of oxygen on Earth is produced through photosynthesis by plants and algae, living things. And the absence of photosynthesis and the absence of life, Earth's atmosphere would be mostly dominated by carbon dioxide and nitrogen.

So the idea of being well, if we see an oxygen-rich planet a place where maybe you and I could comfortably breathe, maybe it means that there's plants there and that there's life there. There's life - well, from the equivalent plant anyway. Something producing photo - oxygen photosynthetically.

Another classic example is methane. Methane, again, on Earth is almost entirely produced by organic living processes whether that's from cow farts or swamp gas from methane-producing bacteria in swamps, it's almost all biologically produced. There are few geological ways of getting it, but they're in the minority.

There's also even more sphere compounds, like, DSMO, Dimethyl Sulfur Oxide, again, almost entirely produced by living organisms. You don't see non-living reactions produce these gases in any large quantity.

So the general idea at least at first was, okay, we should look for these gases. They can almost sort of be a smoking gun. However, we ran into problem - oh, well - and I should say that there's another way of approaching this too if you turn to **Slide 6** is that you can also look for these trace gases not just as in terms of whether or not they're present or not, but also in terms of how they change over time if you've got good enough data resolution that you can do this.

For example, here on Earth while carbon dioxide can be produced very easily by non-living processes, the amount of carbon dioxide in the atmosphere fluctuates annually in a way that is entirely due to living systems.

Specifically, the fact that most of our planet's land mass is located in the northern hemisphere and as a result during northern summer, more carbon dioxide is drawn up by plants than it is during summer in the southern hemisphere.

Notice you see a dip in the amount of carbon dioxide every northern winter. Presumably, if we could get long enough time series of data of a planet that is take a whole bunch of observations of the planet's atmosphere over a long enough time period, we might be able to see these trends.

And again, that would certainly be suggested that there might be a biosphere present. Now, admittedly this one is a little sketchier since we have to assume that, A, that there's a non-uniformed distribution of land mass that essentially all of your land or whatever supports your photosynthesizing organisms is all in one hemisphere and not the other, and that the planet in question has seasons, which it may or may not if it has no axial tilt.

It's probably going stay pretty much the same condition year-round and you're not going to see the changes, but still again, if this is something a pattern we see in terms of - in a long-term observation of a planet, then yes, it'd be suggested that something interesting is going on there.

However, there are problems with trace gases and if you go to **Slide 7**, you will see the first of them. Turns out photosynthesis isn't the only way to make oxygen.

Sunlight under certain - essentially under high U.V. conditions is really good at it. Essentially, the energy from the sun goes in and breaks apart the bonds between the hydrogen and oxygen in a water molecule and separates them out and you get hydrogen oxygen.

The hydrogen is usually lost space because it's the lightest element, so it just basically kind of floats to the top of the atmosphere and zooms away, but the oxygen's heavy enough that it sits around.

And based on simulations and also some lab work, we've determined that actually just through enough sunlight or starlight, in this case, alone if you have a planet that has a large quantity of water on it, you can get a very oxygen-rich atmosphere without necessarily having plants or life in general. It's all through this purely non-biological molecule-splitting process via sunlight.

So obviously, this is an issue and the concern is that we may run into this problem with a lot of the trace gases we're looking at that they may not be smoking guns after all and we may not be able to tell if we see a planet has oxygen, for example, whether or not there's actually a biosphere present or whether it was one of these non-biological processes that generated the large quantity of gas in the atmosphere.

So that is probably one of the biggest hurdles with this particular approach. Another - oh, I should - yes, and another problem is that, in some cases depending on what gas you're looking at, conditions on the host star itself can mimic the spectral signature of the gas in question.

Sun spots or star spots, for example, can sometimes mess with the spectral data of getting a planet's atmosphere composition, which is particularly worrisome when you're dealing with types of stars like Red Dwarves, which have a very large percentage of sunspots and some are phenomena.

So in that case you may get Spectra telling you oh, there's lots of oxygen in here and there actually isn't. It's just an interference caused by the sunspots on the planet's host star, which obviously would be a real bummer.

And lastly, if you go to **Slide 9**, we run into another problem and that, and some of you may have noticed this already, is that this is all predicated that whatever biosphere we're going to look at is going to have chemistry that is similar to our own. That is, it's carbon-based, it takes in carbon dioxide and photosynthetically converts it to oxygen, and then we're all currently taking in some oxygen and metabolize it and breathe out carbon dioxide, and we don't know if that's necessarily going to be the case.

You could potentially have biospheres where the atmosphere is dominated by another gas or uses different chemistry and it's particularly worth thinking about since here on Earth even for the first two, three billion years that our planet's been inhabited by life, it did not have an oxygen-rich atmosphere.

Oxygen and photosynthesis was developed only relatively recently last 700 million to 1 billion years. If you were to take a telescope and look towards Earth for most of its history, the atmospheric composition and spectra would look very different from what we see now.

And if that's the case everywhere, then statistically most inhabited planets may not have an oxygen-rich atmosphere if it takes that long for organisms to evolve the ability to produce oxygen via photosynthesis.

Instead, there may be these carbon dioxide nitrogen-dominated atmospheres. And while we can speculate about the nature of what sort of biochemistry might work under those conditions, again, we do have plenty of microbes here on Earth that can survive and thrive without oxygen and that gives us a general idea of what they might produce in terms of trace gasses.

There are quite conceivably other alternative biochemistries that we haven't thought of just because it's so outside of what we normally deal with. So that kind of brings out the problem, again, with the idea of trace gases. It's very possible that we could look at a planet and see very much a smoking gun trace gas, but we won't recognize it for what it is because it's produced by a type of biosphere that we haven't thought of yet.

So when we're dealing with the sort of question of life in the universe, we can't necessarily afford to be narrow-minded or tropinistic about what sort of biochemistry we might encounter.

So that's a major drawback as well of sort of this trace gas approach. Yes, and if you go to **Slide 10**, I go into more detail about that. There's been a lot of concern about, for example, hydrogen-dominated atmospheres which you would potentially see relatively early on in a planet's evolution as well as in when dealing with planets that are significantly more massive than Earth. The so-called, Super Earths, which would be large enough that instead of having all that hydrogen in space like I mentioned earlier, as happens on Earth and other Earth-like sized planets, it actually gets retained and you could actually build up quite a large quantity of hydrogen.

And while we are not really sure how biochemistry would necessarily work under those conditions, we have some ideas, of course, but again, it's very different from the biochemistry we're used to and we may not know necessarily what would be the optimal trace gas to look for in terms of a biosphere on a hydrogen-dominated planet.

Same thing's true for CO2 dominated. We have a little bit better idea because, like I said, for most of Earth's history, its atmosphere was carbon dioxide-dominated, and the same thing goes for a planet that has a nitrogen dominated atmosphere.

We have some general ideas, but we're not really sure. Now, if you go to **Slide 11**, for the - this particular problem of not knowing necessarily what trace gases are important, there is a potential solution or tool, anyways - and this is what my research is primarily focused on, is applying a branch of mathematics known as Network Theory.

And the way you do this is essentially if you look at Figure A, what you do is you draw the list of all the chemical reactions that occur in a planet's atmosphere and you can usually figure this out either though empirically observing the atmosphere.

Like, you might say do for Mars or, again, potentially some of these exoplanets in the next 10 to 20 years, or through thermodynamic simulations if you know the planet's temperature and the pressure and the mass, you can figure out approximately what gases are likely to be present and what reactions are likely to be occurring.

You can generate this list of reactions and then you can convert it into essentially a network where every species involved is a point in the network. So, hydrogen or chlorine or oxygen or whatever and the reactions between them are links between these points and that's sort of drawn up in Figure A is how this is done.

Now, you may be wondering to yourself why would you want to do that? Well, it turns out -- and this is very, very preliminary data -- that for when this has been done for planets - or the atmosphere planets in our own solar system, something interesting happens.

Figure B, the figure in the middle, is the network for the atmosphere of Mars. As you can see, it just kind of looks like this sort of jumbled messy ball of spaghetti.

And most planets in our solar system that have an atmosphere, that's what their network looks like. It just kind of looks like this lump of lines.

Figure C is the network per the atmosphere of Earth and you can see that there's something odd going on here. It's much more organized, it has - it's referred to having a structure that's modular which means that you can break it into smaller pieces that sort of clump together and also, smaller pieces feed into large pieces.

And these are kind of interesting signatures and this is sort - again, what I'm doing my dissertation on and most of the research that's been done on this odd property of Earth's atmosphere - and there isn't very much. There's only been a few papers on it. It hasn't really been able to explain necessarily why this is happening.

It doesn't help that most of the people who have done it haven't been planetary scientists or astrobiologists. They've been network theorists who basically just did it to see what would happen and thought it was cool that they got a good result, but didn't really think about the potential mechanisms behind it.

But our hope is that this sort of pattern may actually not just be as specific to Earth, but may actually be sort of a universal indicator of the presence of a living system.

And one of the reasons we think this is that this sort of system where you have a whole bunch of points that connects to one point and then that point feeds into another point that has a whole bunch of other points feeding into it is referred to sometimes as being a Scale 3 network.

Think of, like, the Hub and Spokes system for airports and airliners. That's a classic example. You have a couple of points that have a whole bunch of links to outlying points, but most points don't have that many links to other points.

And the interesting thing is you also see this the pattern and the chemical reaction networks that are involved in biological metabolism and the idea that that might be the case is that there's actually some advantages to having this arrangement compared to just sort of having stuff connected to each other randomly.

Specifically that if on by chance if one of those points is knocked out or deactivated or destroyed, or whatever, then it's not going to disrupt the overall structure of the network because, again, statistically the odds of you knocking out or damaging one of those points that has a whole bunch of other points connecting into it is relatively low in a per point basis since you might have a hundred points think of it, like, a hundred airports, but only five or six hubs.

If one of them is going to get snowed in statistically for example, the odds of it being one of the hubs out of those hundred is relatively low. So as a result, we're kind of wondering if this sort of scale-free network structure might be something that happens universally with living systems and that it's going to happen no matter what sort of biochemistry you're using.

Also, it could potentially allow us to avoid the false positive problem with, say, non-biological production of oxygen. If we see a lot of oxygen, but we don't see the sort of network topology or shape show up when we run the analysis of the other gases in the atmosphere, we might be able to assume that, no, this is oxygen that's been produced non-biologically.

Again, this is very, very, very preliminary. Right now, we're just trying to get the code working and seeing when and where these sorts of patterns show up and where they don't show up.

So we're a long way from saying that - oh, yes, this is a definitive way of determining that there's life or not, but it's interesting enough that we're definitely very excited about the potential implications of it.

So stay tuned. Hopefully in the next couple of years we'll have a better idea of what this sort of network structure means and how significant it is.

Now, there are other ways aside from trace gases of potentially seeing the presence of life from Earth from a telescope, if you go to **Slide 12**, another way of thinking about trace gases - and I actually should've done this earlier. I'm trying to move my slides around, but oh, well.

Is thinking about equilibrium and disequilibrium. So in this case, you're not really thinking about which gases are present or not just by themselves. You're also thinking about how they react with each other.

So the idea with chemical equilibrium is that left to your own devices, chemical reactions and things in general following the second model of thermodynamics will tend to go for the most intermixed, most disorganized sort of just most muddled state, and a classic example is if you drop food coloring into water, eventually that food coloring will evenly disperse throughout the whole glass of water and you can kind of see a figure of that on Page 12.

And that the idea of being as sort of an analogy that chemical reactions will try to eventually approach the state in which all the thermodynamically possible chemical reactions have occurred and that the products of those reactions are kind of in the most muddled state.

And essentially once you get that equilibrium point you just kind of sit there and nothing really interesting happens.

The thing is living systems by definition don't like to hang around equilibrium. If your body's at chemical equilibrium, it means you're dead. We actually exploit this equilibrium in order to exist essentially to keep living. That's sort of chemically speaking powers our bodies. It's our major source of energy.

And this holds true, we think, on a planetary scale as well. If you advance to **Slide 13**, so the first person to really think about this was this guy, James Lovelock. He came up with the Gaia Hypothesis, which you may have heard of.

And his basic point was that living systems because of the fact that they tend to be like being away from chemical equilibrium because that's where the interesting stuff happens, are going to produce an environment that is away from chemical equilibrium.

As a result, this would be a potential way of determining whether or not that there's life on the planet. In fact, he originally came up with it because back in the 60s he was asked to see if he could figure out a way if there was life on Mars or not and he took one look at the atmosphere and it's a composition as it was known at the time, which is an important point that I'll get to.

And said nope, there's probably nothin' really living there because the atmosphere's at chemical equilibrium. And so this ideas been around for a while, but it does point - bring out a really important point and it's also been applying to here on Earth looking at our atmosphere.

We have two molecules, oxygen and methane, and normally at equilibrium if you have an auction rich atmosphere, you're not going to see any methane. It's all going to react with the oxygen to become carbon dioxide.

But the fact that we have this equilibrium state where we have two compounds that would normally react with each other and in this case, to extinction with a case of methane suggests - correctly that there is a biosphere that's actively pumping out methane.

And you can see this example, this **Slide 14**, just showing you the reaction. So again, this could be a potential way of looking at the atmosphere of planets. Not just looking at specific trace gases, but seeing which trace gases coexist with other trace gases and whether or not they are gases you would expect to see a chemical equilibrium or not.

If they aren't, if again, if you have the example of oxygen and methane, then it suggests that there is something actively keeping the atmosphere from reaching equilibria and, again, here on Earth anyways and we're somewhat unique in the solar system that thing is life.

Incidentally, if you go to **Slide 15**, this is why everyone get so excited whenever anyone talks about there being methane on Mars. Has been reported several times over the last decade or two and general consensus seems to be now that it really is there. It was in dispute for a while because it was such faint traces that they weren't sure if they were actually detecting it or not.

But the reason everybody gets so excited is that looking at the normal atmospheric composition of Mars, you should not expect to see methane at equilibria. It should be oxidized CO_2. Not by oxygen, but by similar compounds and by ultraviolet light.

Now, there are non-biological ways of producing methane and there have been a number that have been speculated, everything from water, rock, mineral interactions to lightning strikes to static electricity and dust particles and sand storms, but the point remains something has to be actively producing the methane in order for us to be detecting it.

So something weird is going on here, something that we wouldn't necessarily expect. It may not be life. Statistically it probably isn't, but it's still worth taking a look at particularly since, again, here on Earth most of the methane comes from living things.

So just as an example of the sort of idea of equilibrium that’s a little bit closer to home, methane on Mars is a really good one. So you're bored of trace gases yet? Well, I hope so because we are moving on to a different approach. Go to **Slide 16**. Okay.

So you've got a planet, you're looking through the telescope, you can't make out its surface features, they're too far away, all you can see is the light that's being transmitted through its atmosphere by its host star.

You can see something else aside from gasses too and that is potentially you can see pigment which you all probably know. Pigments are pretty much anything that has a noticeable color to it or substance anyway and they are very, very heavily used in biology.

I mean, you can get them non-biologically as well, but there are some such as chlorophyll which I'm sure you're all familiar with that are exclusively produced by biology so far as we know.

And the interesting thing is under certain circumstances even though you may not be able to make out the surface features of an exoplanet, you won't be able to see forests or anything. You can actually detect whether or not there's large quantities of chlorophyll or similar pigments of it.

If you go to **Slide 17**, you can see an example. This is referred to the Red Edge Effect. Essentially, what it is is that, again at least here on Earth chlorophyll is very good at absorbing wavelengths of light that are sort of in the blue range, as well as, sort of in the orange-reddish range.

The reason chlorophyll looks green to us is because that's the only wavelength it doesn't absorb, that's reflected back. Furthermore, chlorophyll is also very good at reflecting infrared lights.

It's thought that this is because it helps prevent the plant cells from overheating, which would be a useful feature. So it turns out, again, based on both simulations and from actually if you recall correctly from space probes that we sent to the outer planets and then looked back on Earth, like, say New Horizons or Voyager, the effect of all that chlorophyll, because we've got a lot of it here on Earth, is that it actually absorbed enough light in the blue and sort of yellow/orange/red range that it's actually affecting the light that is reflected off Earth from the sun.

And that furthermore, it also causes an increase in the amount of infrared light that is reflected off the planet from the sun, hence the red edge is because you see the sudden spike that you wouldn't necessarily see otherwise.

So again, we're making a lot of assumptions here that essentially you do have enough chlorophyll for this to work and that you're going to be properly aligned that you can see it- the planet and us and the star may not be lined up correctly, but still, it would be very, very suggestive if you saw this sort of spectral signature where you have a bump in the green range from chlorophyll and a whole lot of infrared light from the reflected heat of the chlorophyll molecules.

Now, if you go to **Slide 18**, now you may be thinking that oh, wait, I thought you said that oxygen and photosynthesis was only discovered relatively recently here on Earth in the last billion years.

You're right from most of the time that Earth has been inhabited. It has been dominated by non-oxygen producing photosynthesis and that uses different pigments and also uses different molecules, a classic example of non-oxygen producing photosynthesis is the type that purple sulfur bacteria use for example, and as the name suggests, they are purple and the pigments they use are sort of a purple or a reddish.

But it turns out that you can still see these sorts of spectral signatures. They're in a slightly different place, but they can be calculated. If you use a different pigment that absorbs the different frequency of light even if it's not producing oxygen.

So this is a pretty handy tool. Again, there's a lot that we don't know because there are a bunch of different pigments one could potentially use and that's not even getting into what the wavelengths of the star is sending out because that's going to determine which pigment is going to be most sufficient at capturing stellar energy.

But it's still relatively trivial to come up with the spectral signature you would see from a planet that's dominated by something similar to purple sulfur-producing bacteria that's all purplish.

So again, this would be a lot harder from an engineering point of view to pick out since you have to have really good resolution and probably a lot of observation to know for sure that that's what you're seeing, but on the other hand it would be probably a much surer bet that you're seeing the signs of life compared to, say, some of the trace gas biosignatures that I mentioned earlier.

Along those lines, if you go to **Slide 19**, so this one is a little bit out there, but it has been seriously discussed within the field is that not only could you potentially look for pigments like chlorophyll or bacteria rhodopsin, which is what purple sulfur-producing bacteria is. You could also look for organisms that glow.

In this case, the picture's, I think, of ghost shrimp or it's bioluminescent algae, one of the two.

There are quite a number of organisms on this planet that for one reason or another will produce their own light and theoretically if you had enough of it, it would produce a signal that you could see that with insolence of spectra that you would get from the planets.

Now, again, this one's kind of out there because you would need a lot. You don't know if necessarily organisms are going to evolve that ability on a particular planet.

Like I said, organisms have evolved it for a bunch of different reasons on our planet and it's not super widespread and you'd also have to hope that they're admitting at a wavelength that's useful to you and that you can detect, but still at least if you saw some really weird spikes in your planetary spectra and they happen to line up with a light-producing compound like luciferase that we see here on Earth, it would be pretty telling that something weird is going on there.

So again, this one's kind of far out, but I thought it was cool and I thought I'd mention it. So going to **Slide 20** just to sort of to wrap things up, so as you might've gathered, this is not an easy problem to solve. Having to take a very, very limited cross section of the data from a planet and trying to extrapolate from that a very, very complicated answer to a very, very complicated question.

And also, I should note that, again, this is very much cutting edge. This is at the margin of what we are currently capable of observing with the current technology. I'm sure that will change with time; however, it's worth noting that at least within the field, I wouldn't necessarily hold your breath.

At a biosignatures conference I was at back in November, they did an informal poll about whether or not we would detect life on an exoplanet within the next 30 years. And while it was fairly evenly split, the winning answer was no, we won't. We won't quite have the technology by then.

Fifty years out, people were a lot more optimistic, but 30 years out we may not have enough data and we may not have quite enough high resolution to really do the analyses that we need to 100% confidently assert that an exoplanet has a biosphere on it.

And as you may have also gathered from the different methods I talked to is that a lot of them have weaknesses and that to really be sure about this, we're probably going to need multiple lines.

So it's not just the matter of seeing a trace gas or seeing a red edge. You'd probably want to make sure that you're seeing both oxygen and methane on the planet, add this equilibrium and a red edge and a chlorophyll bump and maybe some of the network topology as well, you'd want to see a lot of different signs, not just one, but multiple signs that a planet possesses a biosphere before you sort of make the call that, okay, yes, we found alien life in our universe.

So again, this is going to be a difficult challenge. I think the astrobiology field is up to it though, but it could take a while and it's going to take a lot of work and a lot of different very smart people working on the problem from a lot of different angles before we can say with confidence that we've discovered another inhabited planet in our universe. Okay.

So last slide, **Slide 21**, are there any questions?

John Brandt: Yes, this is John Bryant from Albuquerque, New Mexico.

Theresa Mason-Fisher: Hi, John.

John Brandt: Hi. I just had kind of a basic question about your false positives. Given that you recognized false positives, how does that affect your confidence and the data that you're looking at?

Theresa Mason-Fisher: It depends on the context. Generally speaking, everyone's sort of instinct is to assume that when in doubt assume it's a false positive until you can prove otherwise. It's been difficult because this is the possibility of false positives as something we've only really started looking at in the last couple of years.

So we're still kind of assessing as it were how much damage has been done by realizing that oh, crap, there are other ways of getting oxygen on a planet that don't involve photosynthesis.

So to be honest, it's still kind of shaking out, but it has definitely put a lot more emphasis on having multiple lines of evidence that a planet has a biosphere before declaring that hey, we found life.

Adrienne Provenzano:Hi This is Adrienne Provenzano Solar System ambassador, and I had a question. I think it's really fascinating on that scale 3 network diagram that you had and what I'm wondering is this being studied at all in other fields now since you said it came out of network.

Theresa Mason-Fisher: Oh, yes. Yes, network theory has been applied to all sorts of things to biochemistry to atmospheres, as I mentioned, to social networks between people.

Adrienne Provenzano: I'm sorry. Yes, so my question specifically was is that particular diagram, has that particular configuration shown up anywhere else? This seems very science fictiony to imagine that, but has anyone discovered that?

Theresa Mason-Fisher: Not - no, not yet. At least not on other planets, which is kind of when the doubt difficulties of dealing with astrobiology is that we've only got one known inhabited planet to work from. So we never know if what we're seeing is just a fluke or if it's a sign of life and so it just kind of remains to be seen.

Adrienne Provenzano: But it's shown up here with respect to just basic, like trace gas chemistry and in another aspects of ecosystems or...

Theresa Mason-Fisher: Oh, no, no, you see ecosystems, too. You see it in bio - both at, like, the cellular level and also at the ecosystem level, too. That's why we think it might be linked to the presence of light.

Adrienna Provenzano: Okay. Great. Thank you. Very interesting.

Jen Ruliffson: This is Jen with University of North Florida in Jacksonville. You said that methane doesn't exist when an atmosphere is an equilibrium and I was curious if you had any insight with Titan's atmosphere at majority or significantly...

Theresa Mason-Fisher: Oh, Titan's a weird case. So Titan has very little oxygen in it mostly because it's so far away from the sun. So and that's the case you can have tons of methane accumulate.

However - and Titan is not my area of expertise, so take this with a grain of salt. If I recall correctly, some of the gases in its atmosphere are out of equilibrium and we're still trying to figure out why. And some people have even suggested there might be a kind of life on the surface that's causing this, that's not the majority view so far as I know, but it has certainly peaked some people's curiosity.

Jen Ruliffson: Okay. Thank you.

Loretta McKibben: Hello. This is Loretta from California. I was wondering which missions are you using presently for data, like, Kepler and the Hubble and what missions in the future will be used for work like this?

Theresa Mason-Fisher: Good question. Most of the data I've worked with comes from hot Jupiters and most of that's come from Hubble if I recall correctly. We don't have a whole lot to work with because, like I said, this is sort of very much pushing the envelope as it is, but we do have a few data sets kind of that we've sort of extrapolated from.

In the future, James Webb we may be able to get some of that data. It's not primarily what James Webb was designed for, but it can do it. Just barely in terms of looking at a planet that's more Earth-like.

Wfirst if we end up building it, could definitely do it and we were overly excited about that one which is why I'm hoping it'll get uncancelled.

Plato will most likely have the capability; although, it's still in the design phase. There are several other missions that have proposed, one actually called, HabEx, the Habitable Exoplanet imager -- which is designed for that sort of thing -- but that's must further down the pipeline and probably won't be online if it gets built for another decade or two.

Loretta McKibben: So you can't use the Kepler data? That's just for detecting planets? So there's not really a way to see the atmosphere of those?

Theresa Mason-Fisher: Yes, it doesn't - so far as I know, it does not have the spectral resolution to get the planet's atmosphere.

Loretta McKibben: Oh, okay. And I just had a quick question about politics. What do you think about having a new administrator that seems to be more on the man space end than the planetary end? I'm just wondering how can we make sure that this new administrator understands that planets as science is important too.

I've read all of his research, all of his things he's proposed in Congress and none of it even mentions planetary science, like, his Space Renaissance Act, which - I don't know. I just wondered - I used to work at the Lunar Planetary Lab and funding is always a big question.

So how can ambassadors help get the public educated so that they can help support planetary funding?

Theresa Mason-Fisher: I think that at least again, speaking as an astrobiologist, astrobiology's a relatively easy sell to the public. So hey, it's aliens and everybody thinks aliens are really cool usually.

And beyond that though, I think pointing out that most people probably may not be super familiar with spectral imaging of exoplanets and that this is something we're trying to do or more importantly why it's important.

So I think pointing out that okay, if you want to, like, actually find out if there are aliens running out there, this is the sort of technology that we need and the sort of missions we need and that if you want to make this as a priority, this is what you have to lobby Congress for or vote for or whatever.

So I think just making the connection of not only are we doing astrobiology, but this is the sort of stuff we need to be able to astrobiology, making the public more informed about how we do it I think is really important.

Loretta McKibben: Okay. That's a great idea. Thank you very much.

Theresa Mason-Fisher: You're welcome.

Man 1: Theresa, did you mention TESS in the list of missions?

Theresa Mason-Fisher: Oh, I did not and that's - which I feel bad about because TESS is my nickname and I've made so many puns about TESS in the last few weeks it's not even funny.

If I recall correctly, TESS also isn't' really designed to do the sort of atmospheric spectral analysis. It's mostly more similar to Kepler where it's mostly just looking for whether or not there's a planet there at all or not based off of the dip in the star's light caused by a planet passing in front of it.

So while TESS is going to give us a lot of really good candidates to look at with other instruments in terms of figuring out where the planets are located and how big they are, it's not necessarily going to tell us what there atmospheres are made of.

Man 1: Okay. Thank you.

Howard Andrews: Theresa, this is Howard Andrews, a Solar System Ambassador. Have you looked at any interferometry type situations like Keck 1 and Keck 2? Can they provide you the resolution spectrally for atmospheric evaluation?

Theresa Mason-Fisher: I have not looked into it that much mostly just because right now we've mostly been dealing with data from space based observatories; however, in theory, yes, interferometry would be great and that is a very powerful way of getting that sort of information.

And I don't know if Keck 1 and Keck 2 have the resolution necessary, but it would not at all be inconceivable that a follow-on might - and, in fact, like I said, the most likely candidates for the sort of ground-based observatories that are going to give us that information are probably going to be interferometry projects would be my guess.

Although, I should not I am not an instrumentation person. I don't build telescopes, so take that all with a grain of salt.

Howard Andrews: Sure. Thanks.

Theresa Mason-Fisher: You're welcome.

Kay Ferrari: Theresa, it's been a great talk and I have a question for you. On Slide 9, data image that you used is from Star Trek and as I recall, the creature's the Horta.

Theresa Mason-Fisher: Yes, silicon-based.

Kay Ferrari: Silicon-based? That was my question. Is silicon still considered to be the most likely alternative biochemistry?

Theresa Mason-Fisher: Well, they're different way of taking about alternative biochemistry. Yes, people who talk about alternative solvents -- which is basically how water's absolutely critical to life on Earth -- well, what if you used a different liquid, for example?

Some people talked about ammonia or liquid methane. However, in those cases the actual structures- the backbone or the biochemistry, the stuff that everything's made out of is still carbon.

When you talk about silicon-based biochemistry, you're taking out carbon and putting in silicon instead. And the reason people do that is because silicon has some properties that are similar to carbon.

The problem with silicon is that Earth-like pressure and temperature, it's not very reactive. I mean if you have some chunk of carbon, say, coal or something like that, at Earth-like temperature and pressure, it could potentially catch fire which is pretty darn reactive.

On the other hand, if you have silicon dioxide, a lump of sand, it's just going to sit there or a lump of quartz or whatever. It doesn't do much.

With that said though, in temperature and pressure regimes, say very high temperature, very high pressure where carbon-based life would be impossible, in that case silicon being less reactive is actually a benefit.

So, potentially you could get even if they're dealing with a planet that has a partially molten surface and would be utterly inhospitable to us, under those conditions you could potentially or at least conceivably get sort of silicon-based biochemistry, yes.

But again, when - as I mentioned before talking about alternative biochemistry, there is a lot that we don't know and we probably haven't even thought of. So it's hard to say with any real degree of certainty, but it's certainly, you know, conceivable.

Jeff Nee: Hi, Theresa. This is Jeff Nee at JPL. I had a couple of questions about the network on Slide 11. Is that from a paper that we can look up if we want more information?

Theresa Mason-Fisher: Yes, that is from Solé and Munteanu, 2008. Let me double-check. They were the first people to really look at network topology and atmospheres. Again, they were network scientists, not planetary scientists. So they didn't really talk about what might be causing that and how it might be relevant.

Okay. Yes, the paper is Solé and Munteanu, 2004. The title of it is, "The Large Scale Organization of Chemical Reaction Networks in Astrophysics."

Jeff Nee: Got it. Thanks. And can I assume that the - I see four big nodes. Can I assume that's carbon, hydrogen, oxygen and nitrogen or...

Theresa Mason-Fisher: I don't know because they didn't label them. That's one of the downsides to this. Like I said, they were network scientists, not atmospheric chemists. So I don't think it occurred to them that people might want to know that information.

I would assume that it would be oxygen and water and maybe a few other compounds, that yes, are really key to Earth's atmosphere. And part of our ongoing project has been sort of trying to replicate the results which has been difficult because honestly, there were a lot of things they didn't do as good a job as they should have, again, not being atmospheric scientists.

But that was my intuition anyways. And from the replications we have done, usually yes, it ends up being oxygen, usually ends up being, like, the really central one.

Jeff Nee: Okay. So if we wanted a nicer version of that, we should just wait for your paper when it comes out?

Theresa Mason-Fisher: Well, hopefully. You may - it may be a little while. But it's not a bad paper to start with though.

Jeff Nee: Okay. Great. And then just piling on to some other questions, you mentioned that JWST is only going to barely be able to do what you need to.

Do you have an idea of what specifically if you were in charge of mission what would - what could you tweak or what instrument could you add that would make it really, really good for what you'd need?

Theresa Mason-Fisher: I think in the case of JWST, it's partially a limit of the resolution, which is an internal limit of the mirror side, which is kind of the difficulty with this is that part of it is that in order to get high enough resolution to, like, really, really see the planet's atmosphere, you need really big mirrors or you need a whole bunch of smaller telescopes so that there's an interferometer array. One of the two.

So part of it is just the size of the mirror and given that, JWST is probably - is the biggest space-based mirror telescope we built as of yet. I'd be kind of hesitant to say, okay, now we need to make it even bigger.

I think more likely that's why I've been kind of focusing on the next generation. And in some cases it's not that JWST can't do it. Part of the problem is actually logistical.

In order to get enough data that you could do the sorts of analysis that we do, you'd have to have it pointed at a target for a really long time. I think they said based off of the amount of time that's been reserved on JWST between the cosmology people and the distant galaxy people and everything else, we might have time under the current schedule and this will probably change if we go to an extended machine, which we probably will to maybe image two or three Earth-sized exoplanets.

So partially it's just due to the nature of the beast. It's a very time-consuming thing to do and with JWST as being as a high profile instrument as it is, it's going to be difficult to fight to get that time.

And that's why a lot of people are now talking about, like, HabEx or Plato, which are missions that are specifically designed only for doing this so you don't have to worry about crowding out the cosmology people or whatever.

Kay Ferrari: Well, we're almost at the bottom of the hour.

Loretta McKibben: Kay, I found a reference for that. I sent you an email for that paper.

Kay Ferrari: Okay. Thank you.

Loretta McKibben: I think it'll have to be obtained by subscribes to that journal, but anyway, I sent you the link.

Kay Ferrari: Okay. We are at the bottom of the hour now, so I want to thank everyone for joining us today and thank you, Theresa. This was absolutely wonderful. We had a great time. I want to remind everyone that our next telecon will be this Thursday, May 3rd. It will be Universe of Learning and the subject is, Birth of Stars Near and Far. So please join us on Thursday at 12:30 Pacific for our next telecon.

Thank you all for joining us today, everyone, and I hope you have a good evening.

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